FLEET TECHNOLOGY LIMITED

A FLEET AEROSPACE COMPANY

CONTRACT REPORT NUMBER 79128-01-SQ

CONTRACTOR: Arctec Canada

REQUISITION NUMBER 23440-7-9128

A DESCRIPTION OF PREPARATIONS MADE TO CONTINUE TESTING WITH AN EXISTING CONCRETE ABRASION TEST MACHINE

SUBMITTED IN FULFILLMENT OF TASK 1 OF
DSS CONTRACT 15SQ.23440-7-9128

by

G. Comfort

February 1989

Submitted to

Construction Materials Section
Mineral Processing Laboratory
Canada Centre for Mineral and Energy Technology
405 Rochester Street
Ottawa, Ontario
K1A 0G1

Submitted by

Fleet Technology Limited
311 Legget Drive
Kanata, Ontario
K2K 1Z8

MICROMEDIA

32pp

CANMET Scientific Authority: Dr. V.M. Malhotra

TABLE OF CONTENTS

1. INTRODUCTION AND OBJECTIVES.....1

2. DESCRIPTION OF PREPARATIONS MADE.....5

2.1 Test Machine.....5
2.2 Control System and Data Acquisition.....6

3. REFERENCES.....25

APPENDIX A - SPECIFICATIONS

1. INTRODUCTION AND OBJECTIVES

Concrete structures in ice-infested waters may experience damage due to ice abrasion and/or ice impact. At present, there is a paucity of data to evaluate the resistance of concretes of interest to ice abrasion and impact. Furthermore, appropriate procedures and test methods (for evaluating concretes) are not standardized or calibrated with field experience.

In recognition of these needs, the Canada Centre for Mineral and Energy Technology (CANMET) contracted Fleet Technology Limited (formerly Arctec Canada Limited) to undertake a basic research program aimed at the development of a test standard (Nawwar, et al, 1985; Arctec, 1987; Roots et al, 1986). A prototype test apparatus was built during that project. See Figures 1.1 to 1.3. A small number of abrasion and sequential impact abrasion tests were then carried out during that project.

This work has been continued with a project to:

(a) make modifications to the existing machine and to the data collection procedures used previously in an effort to facilitate the conduct of tests.

(b) expand the available database by conducting an additional two tests.

This report describes the work that has been undertaken with respect to (a) above.

Figure 1.1 (after Rawwal, Roots and Berry, 1986)

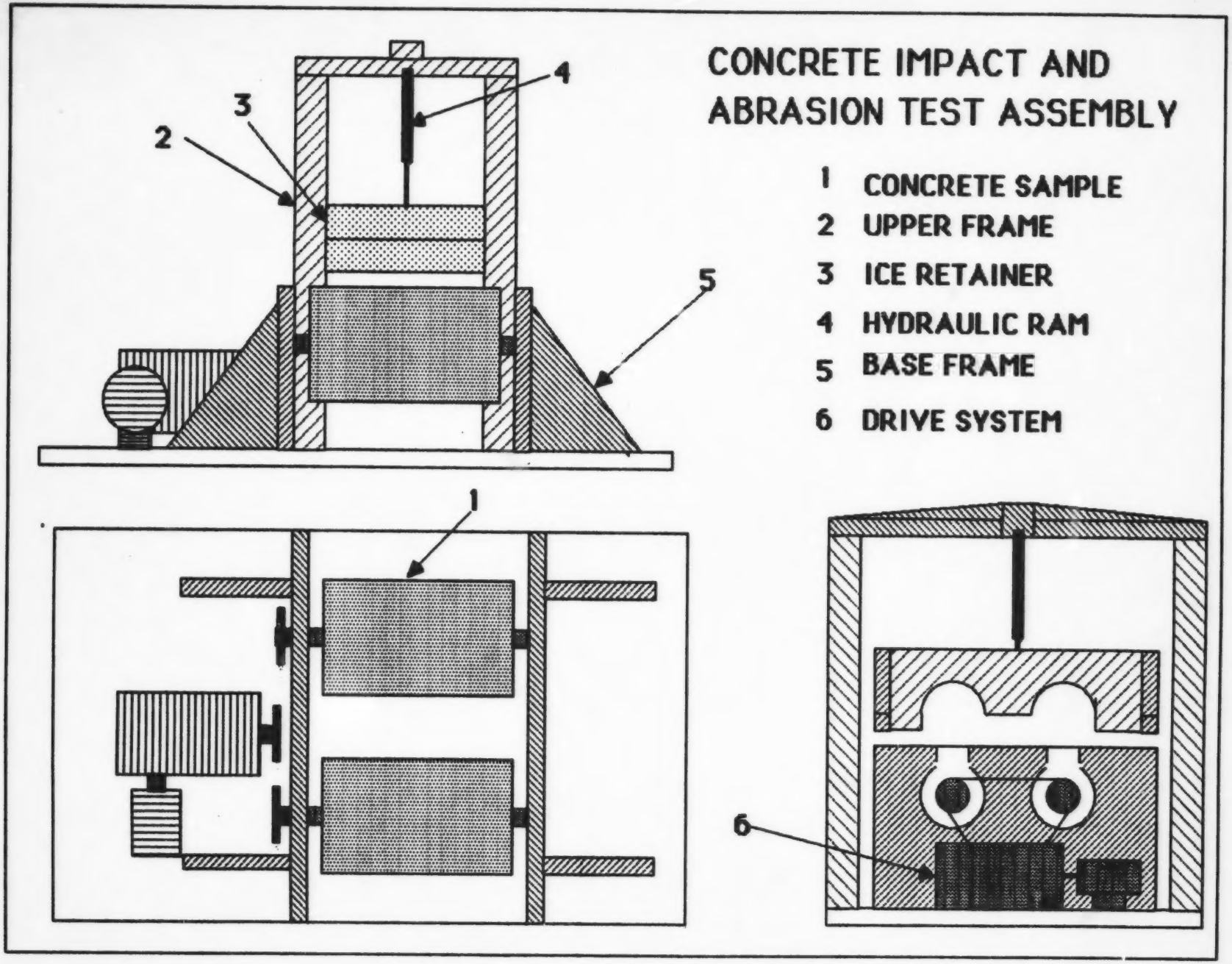


Figure 1.2 (after Nawwar, Roots and Berry, 1985)

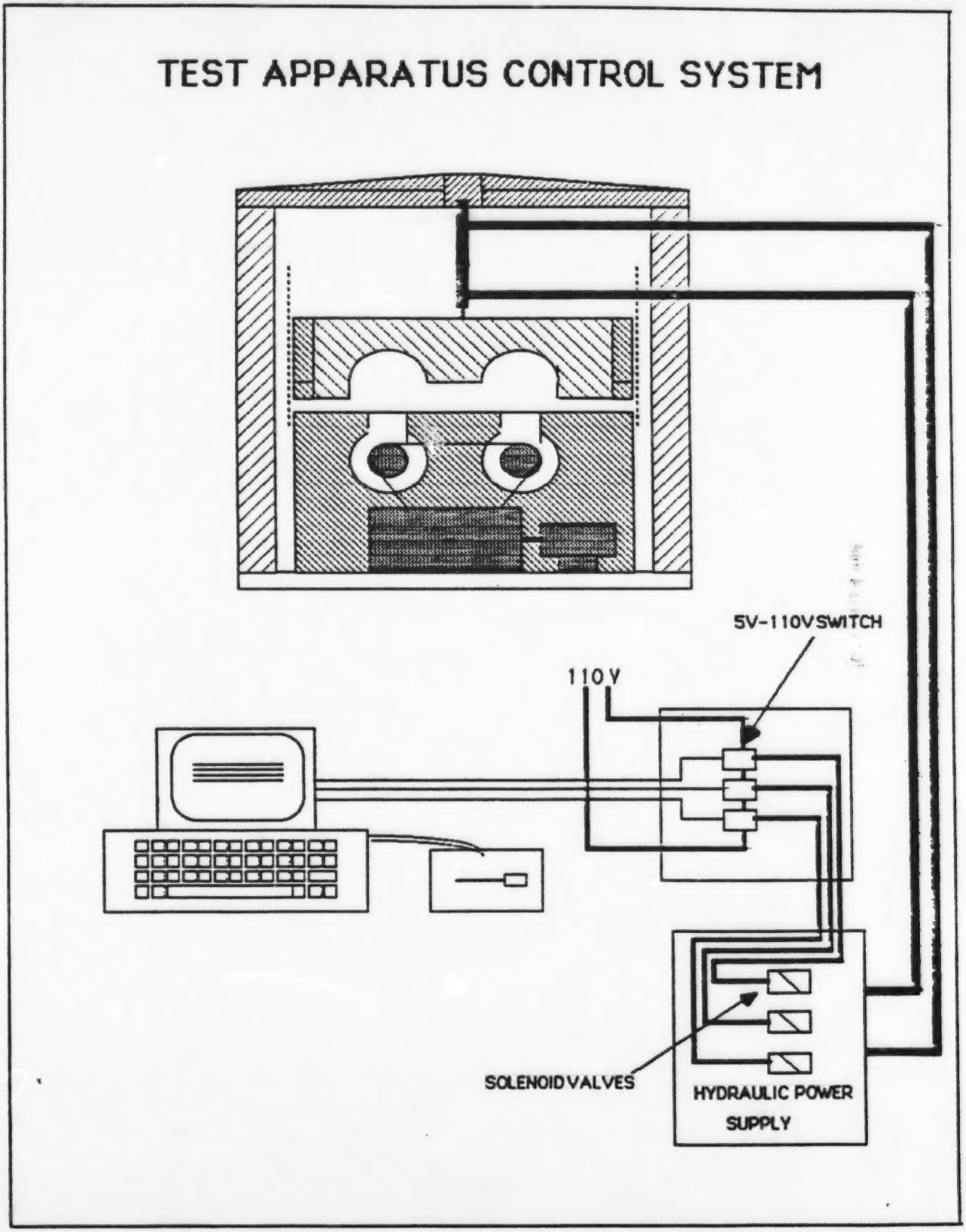
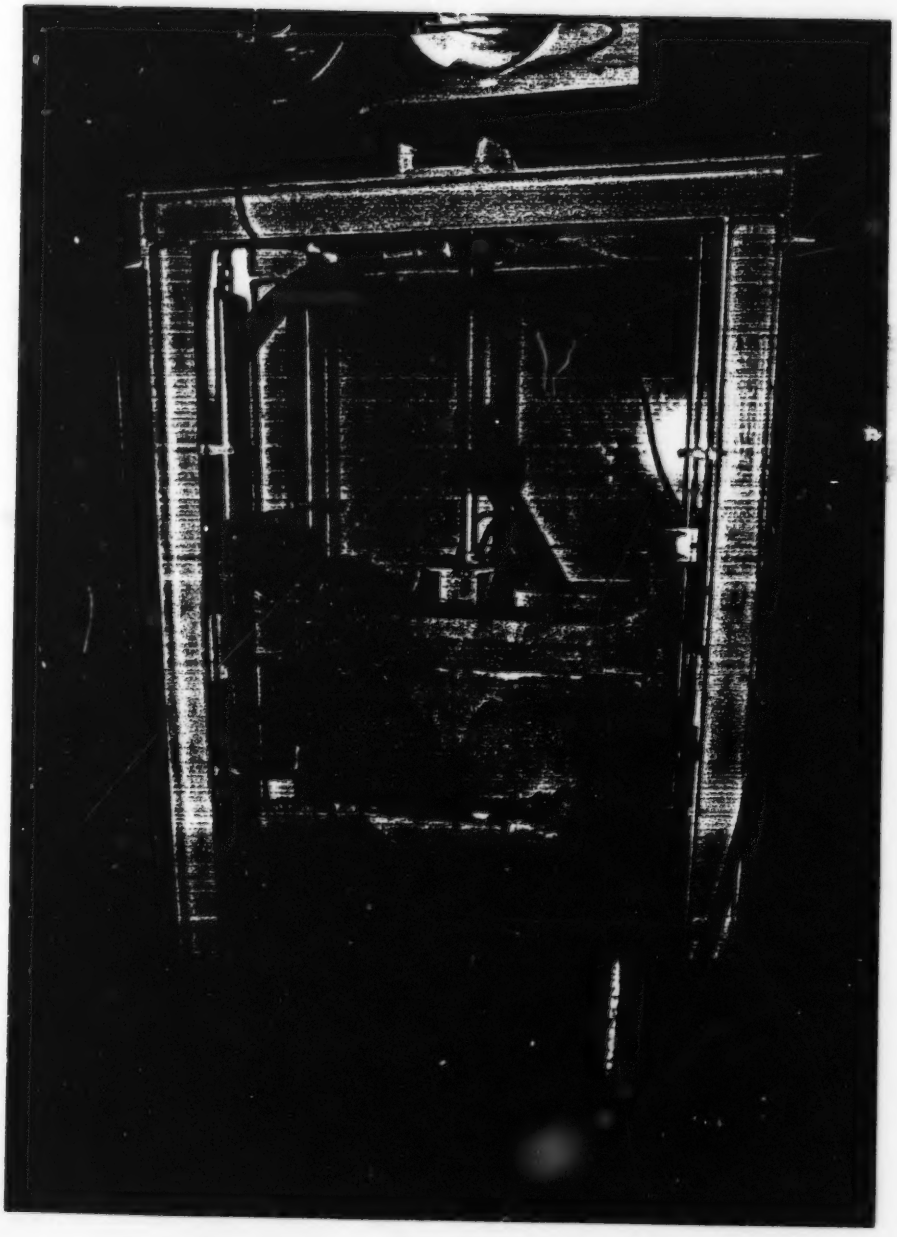


Figure 1.3
Prototype Concrete Abrasion Test Machine
(after Arctec, 1987)



2. DESCRIPTION OF PREPARATIONS MADE

2.1 Test Machine

2.1.1 Initial checkout

The test machine was inspected and lubricated. In general, it was found to be in good repair. The following repairs were required:

(a) one hydraulic hose connector was found to be cracked and was replaced.

(b) the water bath reservoir was rebuilt (as the original plexiglass tank was cracked). It was rebuilt using 6 mm steel plate. Styrofoam panels (of 25 mm thickness) were attached to the steel sides of the reservoir.

(c) the torque-limiter pads were observed to be worn. Replacement pads were ordered and installed midway through the test program.

(d) the test machine frame was secured to the concrete cold room floor using anchor bolts.

2.1.2 Hydraulic system

A downstream accumulator was added to the hydraulic system to reduce the shocks seen by the system during impact tests. This was judged to be necessary as one hydraulic connector was found to be cracked during initial checkout of the machine.

Figure 2.1 provides a schematic of the hydraulic system that was used for the tests.

2.1.3 Temperature control of water bath

The existing temperature control was crude as it consisted of an electric heater and an industrial rheostat. This system did not allow for closed-loop feedback control. The previous tests had shown that temperature control was very important and that precise control was required. If the water bath was too cold, ice formed on the concrete cylinders which prevented abrasion of the concrete. If the water bath was too warm, the ice block became soft and melting occurred.

Hence, the existing temperature control was greatly improved. A system consisting of an Omega RTD and digital indicator and a solid state relay was fitted to the existing heater element in the tank. This provided a system with closed-loop feedback control and a set point resolution of 0.1°C. Specifications for this controller are provided in Appendix A.

2.1.4 Counter-rotation of concrete cylinders

The existing machine was configured to rotate both concrete cylinders in the counter-clockwise direction. This caused the ice block to exert unequal forces on the two concrete cylinders.

The chain drive system was re-configured to counter-rotate the concrete specimens, as shown in Figure 2.2. This was accomplished by adding an idler wheel to the existing drive system.

2.2 Control System and Data Acquisition

2.2.1 Test control

The existing data acquisition and machine control was modified for use with a Hewlett Packard 85B computer. This simplified the machine control and provided greater flexibility.

The modified control system allows for unattended impact tests, abrasion tests and sequential impact and abrasion tests. Key test parameters, such as the number of impacts, the duration of the abrasion period, and the number of impact-abrasion sequences are defined by the user as inputs.

The modified system also provides improved monitoring of the tests. For impact tests, the time of impact, impact number and impact speed is output in hard copy. See Figure 2.3 for sample output. For abrasion tests, the position of the ice block is monitored and is output in hard copy. See Figure 2.4 for sample output. For sequential impact-abrasion tests, both the impact test data and the abrasion test data are output. See Figure 2.5 for sample output.

Automated testing is achieved by using the computer to switch solid-state relays, as shown schematically in Figures 2.6 and 2.7, that:

(a) control the operation of the hydraulic cylinder which raises and lowers the ice block.

(b) control the operation of the electric drive motor which rotates the concrete cylinders.

(c) shut down the machine (and terminate a test) when the ice block is depleted beyond preset limits. (The position of the ice block is monitored continuously throughout the test.)

(d) control the set point temperature of the water bath.

During the conduct of a test, a low water bath temperature (of about +0.2°C) is necessary to avoid icing of the concrete and melting of the ice block.

However, a higher water bath temperature (of about +7°C) is required to prevent excessive ice build-up when the machine is shut down (and hence the concrete cylinders are not rotating). As the machine may be shut down for part of the overnight period awaiting the installation of a new ice block, the computer is used to switch from the low set point to the high set point after the concrete cylinders have stopped rotating. This avoided test delays associated with removing the ice and re-stabilizing the water bath temperature.

The control was accomplished using the same Omega RTD controller (described in 2.1.3) as it has two independent set points. Both set points are manually set by the user.

2.2.2 Wear measurements

The existing set-up for profiling the concrete cylinders (and hence for making wear measurements) was replaced. The previous system was referenced to the frame of the machine which was believed to contribute to inaccuracy.

The new system is referenced to a zero baseline established on the concrete cylinder, as shown schematically in Figure 2.8.

Depth measurements are made with respect to this baseline using a Mitutoyo Digimatic Indicator. This instrument has a measurement accuracy of 5 μm and a visual digital display using Light Emitting Diodes (LED's). Specifications for this instrument are provided in Appendix A.

Depth measurements are made at fixed locations on the sample using a metal locating frame. To make wear measurements, the locating frame is attached to the cylinder at pre-selected profile locations through brass inserts (of the type commonly used for concrete sample strain measurements) set in the concrete. The digital indicator is attached to the frame along a slide rail. A total of ten equidistant locating holes are drilled in the frame (through which wear measurements are made).

During the testing phase of the project, wear data were measured at three profile locations which were 120 degrees apart. See Figure 2.8. Three separate measurements of the depth profile were made at each profile location.

Profile data were logged manually using data sheets. See Figure 2.9 for sample.

For data reduction, a spreadsheet was established on an APPLE MacIntosh computer using the EXCEL program. This spreadsheet presents the raw data, and computes the wear.

These computations are done for two cases:

- **Case 1:** Rav data referenced to original profile reference depths measured at the start of the test. See Figure 2.10 for sample spreadsheet output.

  The following steps are involved in the computation of wear for this case:

  (a) Before the start of the test, the concrete cylinders were profiled three times at each of the three profile locations. These profile data were averaged and input as the "Profile Ref. Depth" for each profile location.

  (b) The average wear at each point along each profile location is computed by averaging the individual measurements as follows:

$$\text{"Avg. Pt. Wear"} = \frac{1}{3}\left[\begin{array}{l}\text{sum of "Profile Depth"} \\ \text{for measurements \#1} \\ \text{2 and 3}\end{array}\right] - \text{"Profile Ref. Depth"}$$

  (c) The average wear along the length of each profile measurement is computed. This is done by first computing the cross-sectional area of each individual profile (i.e. the "Profile Area"). This is done by considering the profile to be a series of trapezoids. The average wear along the length of each individual profile (i.e. "Avg. Wear Over Profile") is computed as:

$$\frac{\text{Area of individual profile - Area of original ref. profile}}{\text{Length of concrete cylinder in contact with the ice block}}$$

  (d) The three "Avg. Wear Over Profile" values computed in (c) above are averaged to determine the average wear for each profile location.

- **Case 2** - Raw data referenced to reference baseline measured at the same time as each set of raw profile data were collected. See Figure 2.11 for sample spreadsheet output.

  The following steps are involved in the computation of wear for this case:

  (a) "Profile Ref. Depths" are input as described for case 1.

  (b) The "Corrected Wear" is computed at each point along each individual profile. This is computed by subtracting the measured "Profile Depth" (listed in page 1 (i.e. Figure 2.10) of the spreadsheet) from the position of the reference baseline established by the two reference inserts on the concrete cylinder. See Figure 2.8.

  (c) The average wear at each point along each profile location (i.e. the "Avg. Pt. Wear") is computed by averaging the individual values of "Corrected Wear".

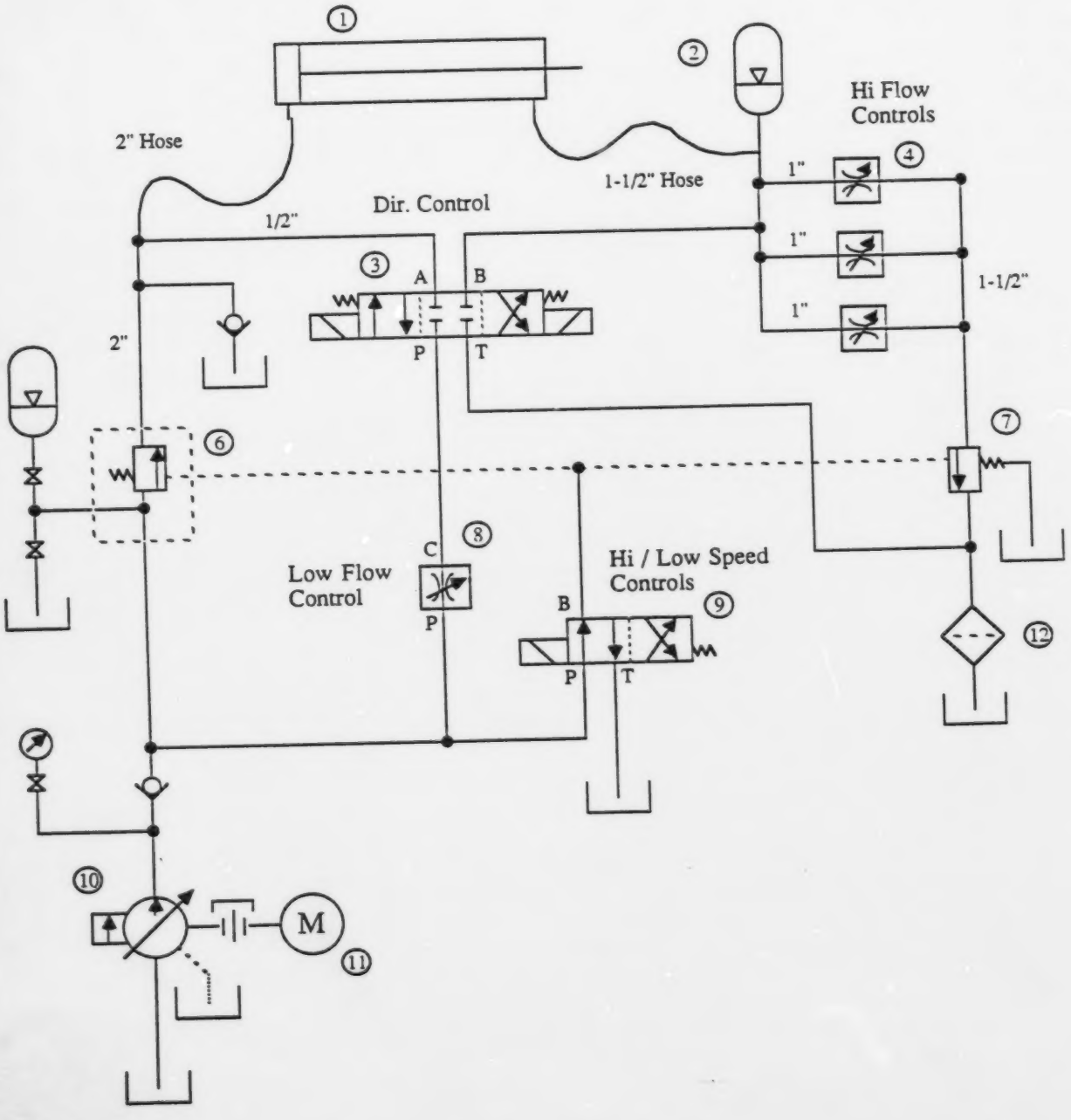
  (d) The average wear along the length of each profile measurement is computed from the individual values of "Corrected Wear" at each point. The cross-sectional wear area (i.e. the "Profile Area") is computed by considering the profile to be a series of trapezoids. The average wear along the length of each individual profile (i.e. "Avg. Wear Over Profile") is computed as:

$$\frac{\text{Profile Area}}{\text{Length of concrete cylinder in contact with ice block}}$$

  (e) The three "Avg. Wear Over Profile" values computed in (d) above are averaged to determine the average wear for each profile location.

These two cases generally give different values for the average wear. For case 1, the raw data for each set of profile measurements are referenced to the original profile data collected at the start of the test. For this approach to provide accurate values of wear, it is necessary to install the locating frame in an identical manner for set of profile measurements, which is difficult to achieve. For example, some debris and/or ice may accumulate in the brass inserts between profile intervals. For case 2, the reference baseline is established at the time of each set of measurements and is independent of the set-up of the locating frame. Hence, case 2 is believed to yield more accurate values.

Figure 2.1
Schematic of Hydraulic System



Note: See table 2.1 for listing of components

Table 2.1 Listing of Major Components of Hydraulic System

No	Item Desc.	Manufacturer	Model #	Parameters
1	Hydraulic Cylinder	Cylindrix	HU-30020-RF	Rod: 1-1/8" Stroke: 16"
2	Accumulator	Sperry/Vickers		Cap: 1 USGal
3	Directional Control Valve	Sperry/Vickers	DG 4S4 012C 50 S324	
4	Flow Control Valve(s)	Sperry/Vickers		
5	Accumulator	Sperry/Vickers	A1-1050-21	Cap: 5 USGal
6	Sequence Valve	Sperry/Vickers	RF-16-A3-10	
7	Back Pressure Valve	Sperry/Vickers	RT-12-AP1-22	Aux Rem Control 'P', Cap.: 75 GPM
8	Flow Control Valve	Sperry/Vickers	FG02 1500 50	
9	Directional Control Valve	Sperry/Vickers	DG 4S4 012A 50	
10	Piston Pump	Sperry/Vickers	PVB5 RSY 20 C 11	5 GPM @ 1800 RPM, Press. 250-3000 PSI
11	Electric Motor			10 HP, 575 V, 10 A, 3 Ø, 1740 RPM
12	Filter			
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				

Note: See figure 2.1 for system schematic

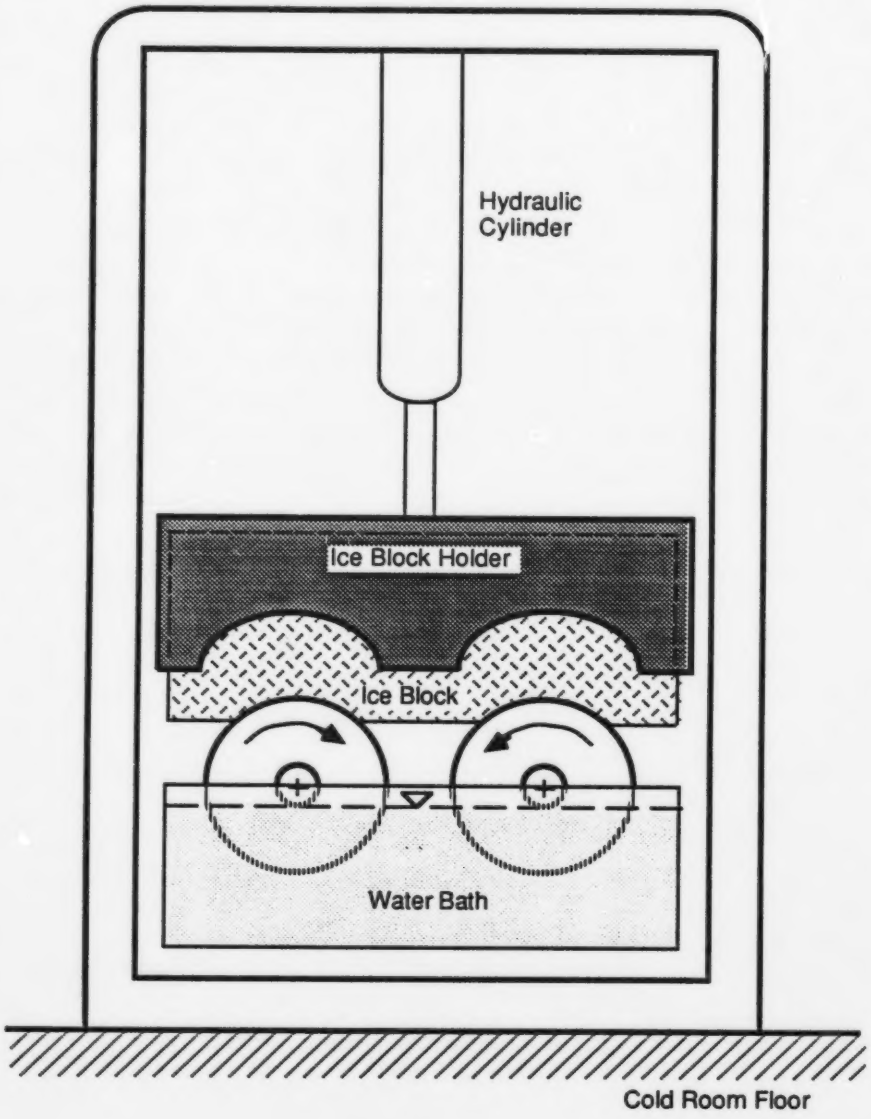


Figure 2.2 Direction of Rotation of Concrete Cylinders For Modified Test Machine

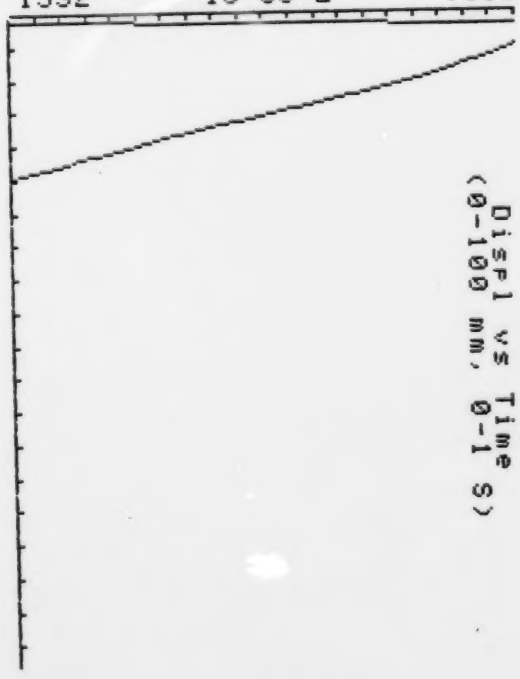
Figure 2.3

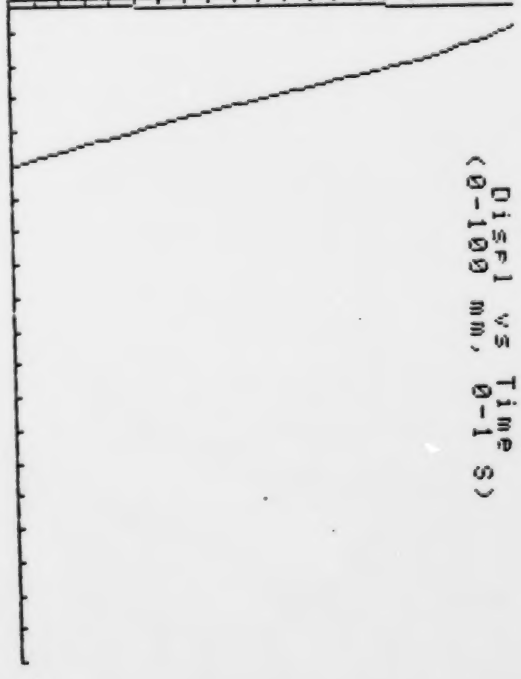
Typical Real-time Output Of Impact-Only Tests

Arctec Canada Ltd.
Impact/Abrasion of Concrete

Date = 311 Time = 16:41:49
Test no. 1 No. of impacts :
492

Imp#	Time	Vel.(m/s)
1509	16:42:29	.046
1510	16:43:5	.050
1511	16:43:40	.050
1512	16:44:15	.050
1513	16:44:51	.050
1514	16:45:26	.049
1515	16:46:1	.047
1516	16:46:37	.047
1517	16:47:12	.051
1518	16:47:47	.050
1519	16:48:23	.049
1520	16:48:58	.050
1521	16:49:33	.050
1522	16:50:9	.048
1523	16:50:44	.051
1524	16:51:19	.050
1525	16:51:55	.047
1526	16:52:30	.050
1527	16:53:5	.049
1528	16:53:41	.048
1529	16:54:16	.050
1530	16:54:51	.046
1531	16:55:27	.047
1532	16:56:2	.050
1533	16:57:10	.046
1534	16:57:46	.051
1535	16:58:21	.049
1536	16:58:56	.051
1537	16:59:32	.048
1538	17:0:7	.051
1539	17:0:42	.047
1540	17:1:18	.051
1541	17:1:53	.048
1542	17:2:28	.049
1543	17:3:4	.049
1544	17:3:39	.050
1545	17:4:14	.048
1546	17:4:50	.048
1547	17:5:25	.048
1548	17:6:0	.047
1549	17:6:36	.050
1550	17:7:11	.050
1551	17:7:46	.050
1552	17:8:22	.050
1553	17:8:57	.048
1554	17:9:32	.050
1555	17:10:8	.049
1556	17:10:43	.048
1557	17:11:19	.047





Note: Above plots show displacement of iceblock vs. time for one impact. Plots shown for every 25th impact.

Figure 2.4

Typical Output For Abrasion-Only Test

```
   Arctec Canada Ltd.
 Abrasion of Ice on Concrete

Date =  1234    Time = 11:57:43
Test no.4
Abrasion time = 15:0:0

--------------------------------
```

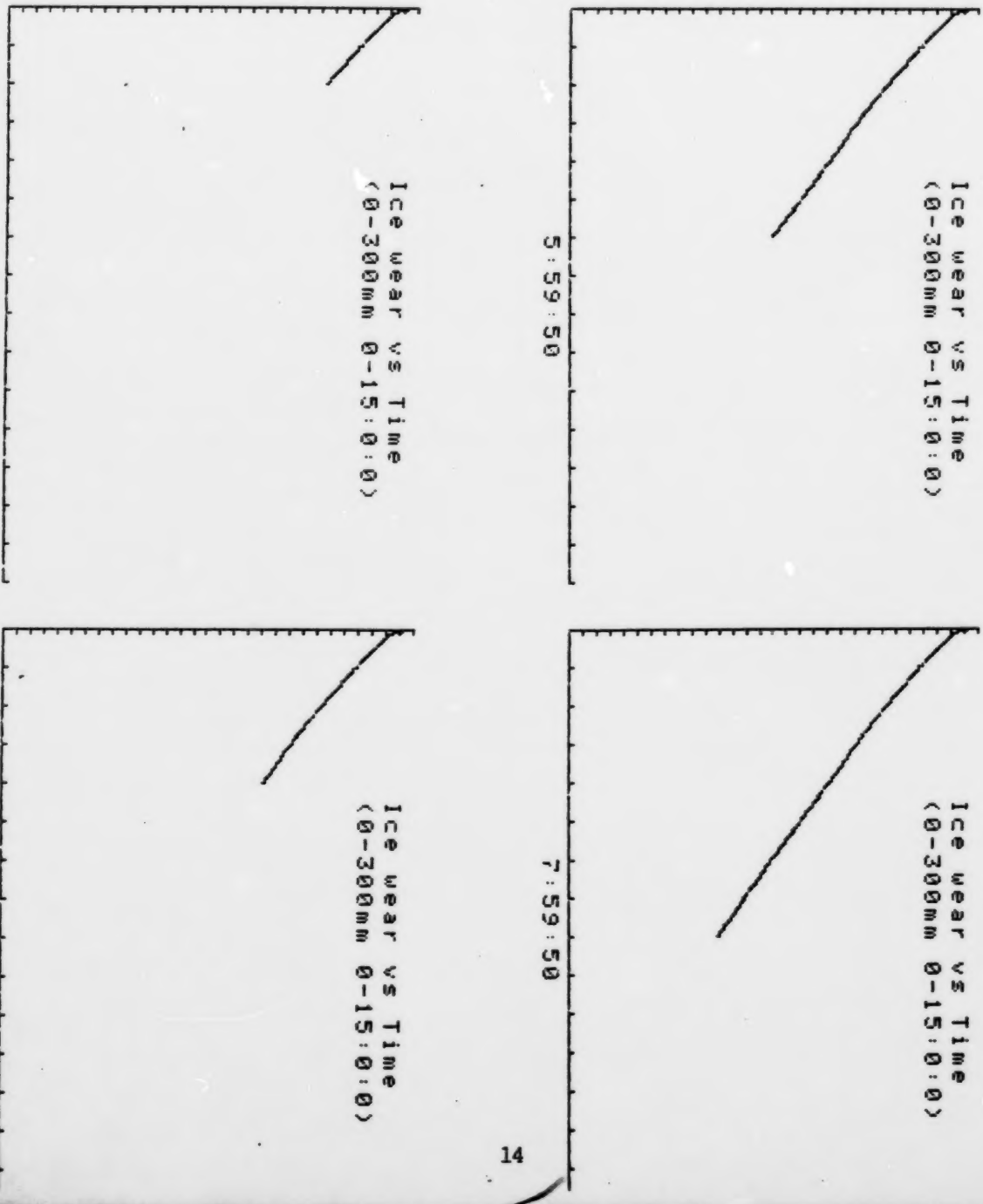
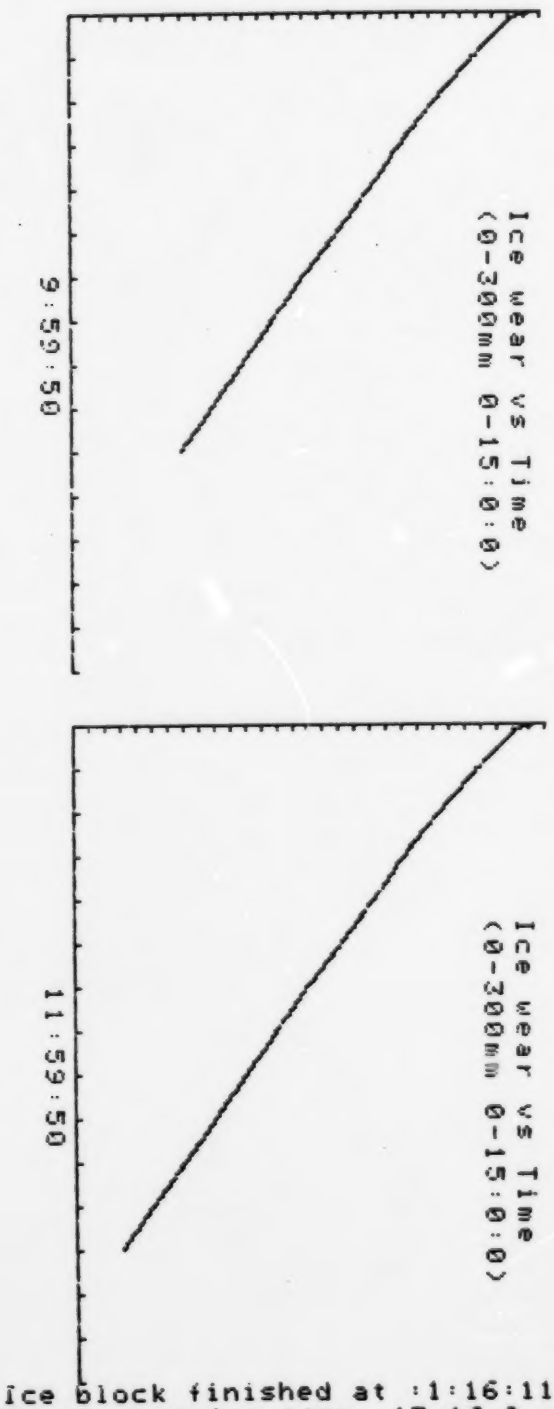


Figure 2.4



Ice block finished at :1:16:11
Total abrasion time :13:16:0

Figure 2.5

Typical Real-time Output For Impact/Abrasion Test

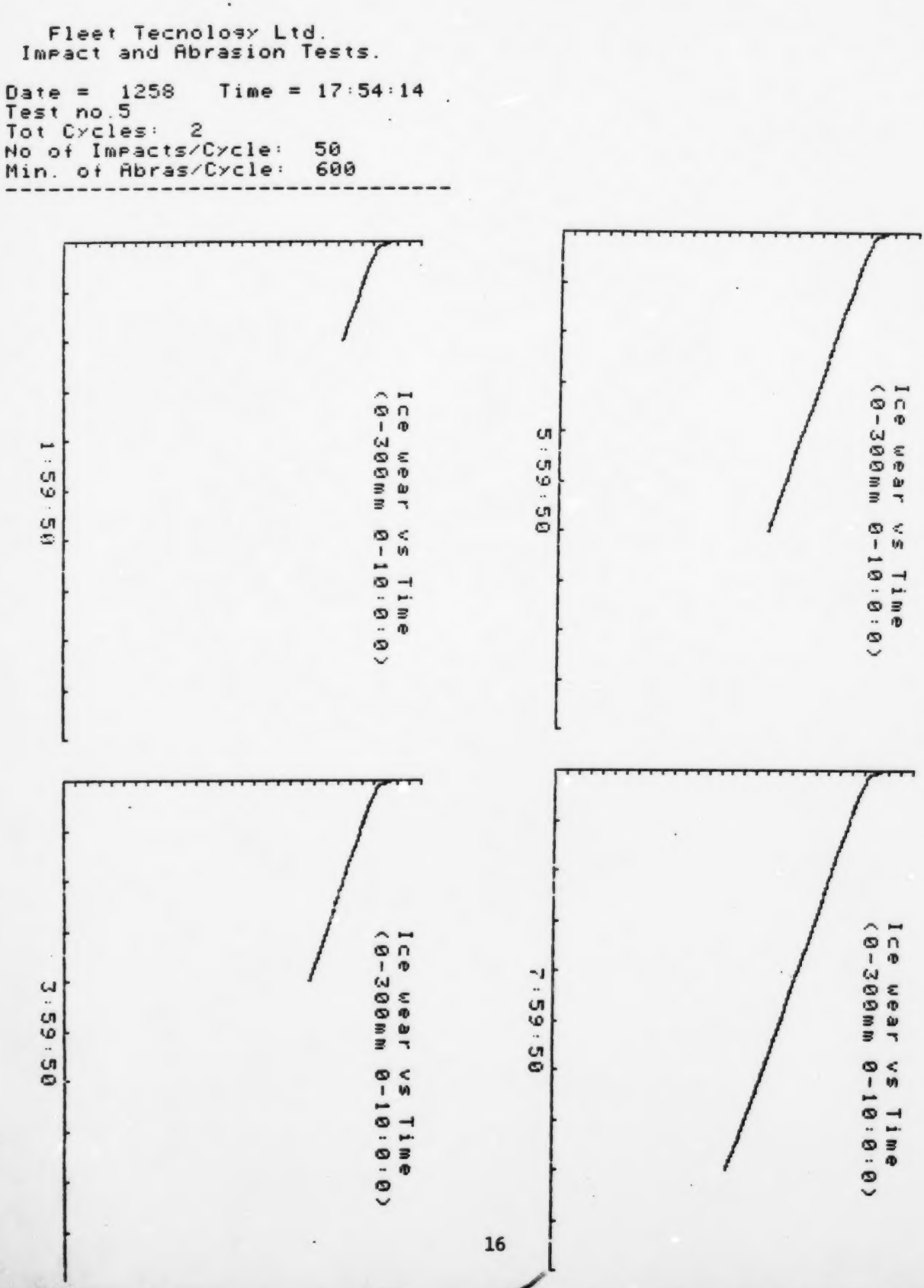
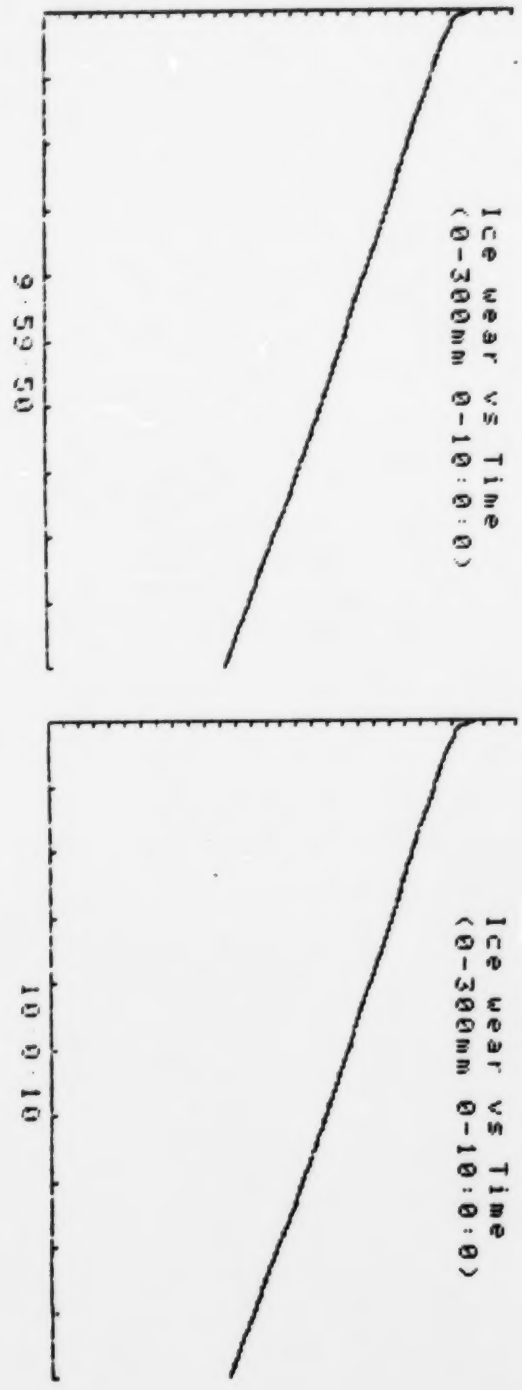
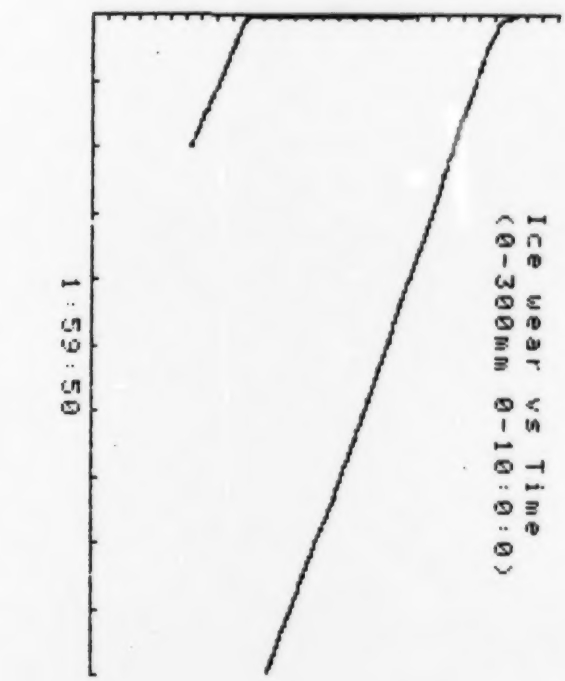


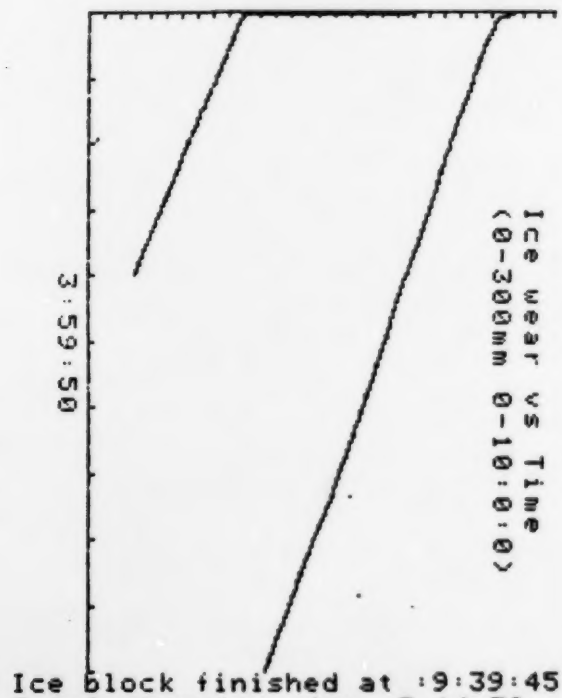
Figure 2.5




```
Impact:   1    Vel:   .984
Impact:   2    Vel:  1.028
Impact:   3    Vel:   .984
Impact:   4    Vel:  1.010
Impact:   5    Vel:  1.037
Impact:   6    Vel:  1.010
Impact:   7    Vel:   .984
Impact:   8    Vel:  1.010
Impact:   9    Vel:   .984
Impact:   10    Vel:   .957
Impact:   11    Vel:  1.010
Impact:   12    Vel:  1.010
Impact:   13    Vel:   .957
Impact:   14    Vel:   .984
Impact:   15    Vel:   .984
Impact:   16    Vel:  1.010
Impact:   17    Vel:  1.010
Impact:   18    Vel:   .984
Impact:   19    Vel:   .984
Impact:   20    Vel:   .984
Impact:   21    Vel:  1.010
Impact:   22    Vel:   .984
Impact:   23    Vel:  1.010
Impact:   24    Vel:  1.010
Impact:   25    Vel:  1.010
Impact:   26    Vel:  1.010
Impact:   27    Vel:   .957
Impact:   28    Vel:   .957
Impact:   29    Vel:   .930
Impact:   30    Vel:   .957
Impact:   31    Vel:  1.010
Impact:   32    Vel:   .984
Impact:   33    Vel:   .957
Impact:   34    Vel:  1.010
Impact:   35    Vel:  1.010
Impact:   36    Vel:   .957
Impact:   37    Vel:   .984
Impact:   38    Vel:   .984
Impact:   39    Vel:  1.010
Impact:   40    Vel:  1.010
Impact:   41    Vel:   .984
Impact:   42    Vel:   .957
Impact:   43    Vel:  1.010
Impact:   44    Vel:   .957
Impact:   45    Vel:   .957
Impact:   46    Vel:  1.010
Impact:   47    Vel:   .984
Impact:   48    Vel:   .957
Impact:   49    Vel:   .984
Impact:   50    Vel:   .957
Cycle:   1    Avg Vel:  .988
```

Figure 2.5





Ice block finished at :9:39:45
Total abrasion time :5:14:30

Figure 2.6

Schematic For Main Control Panel

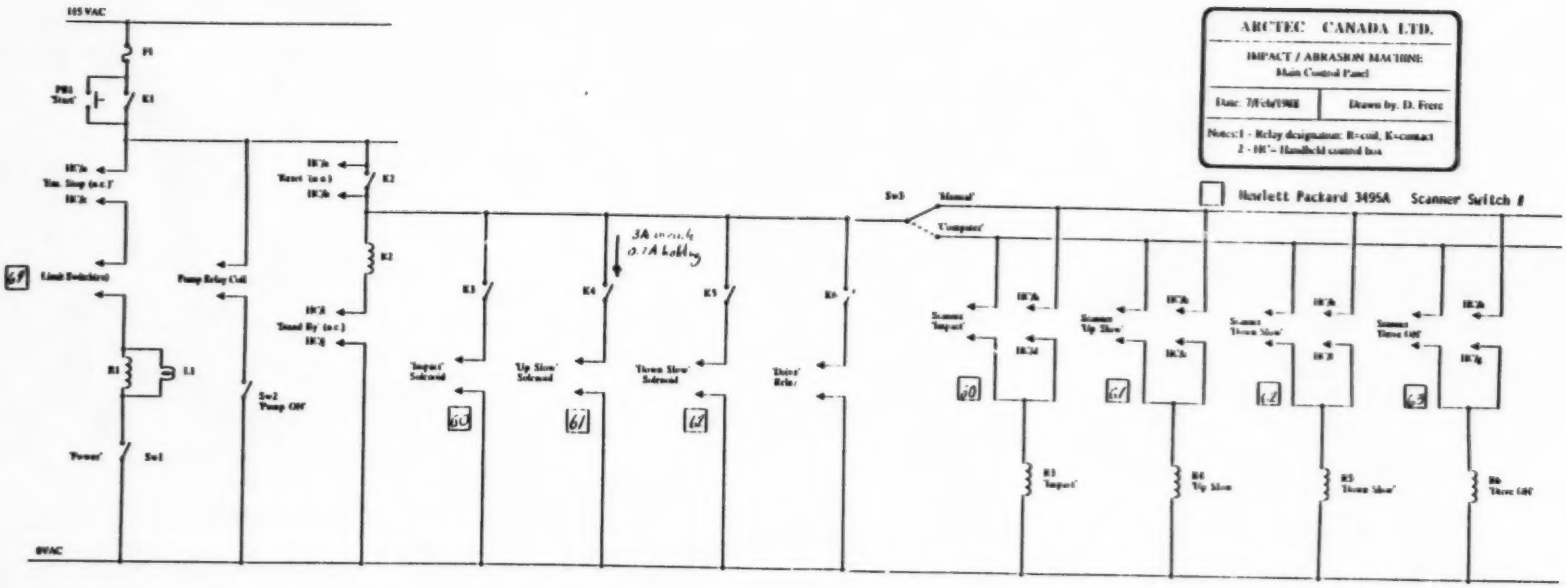
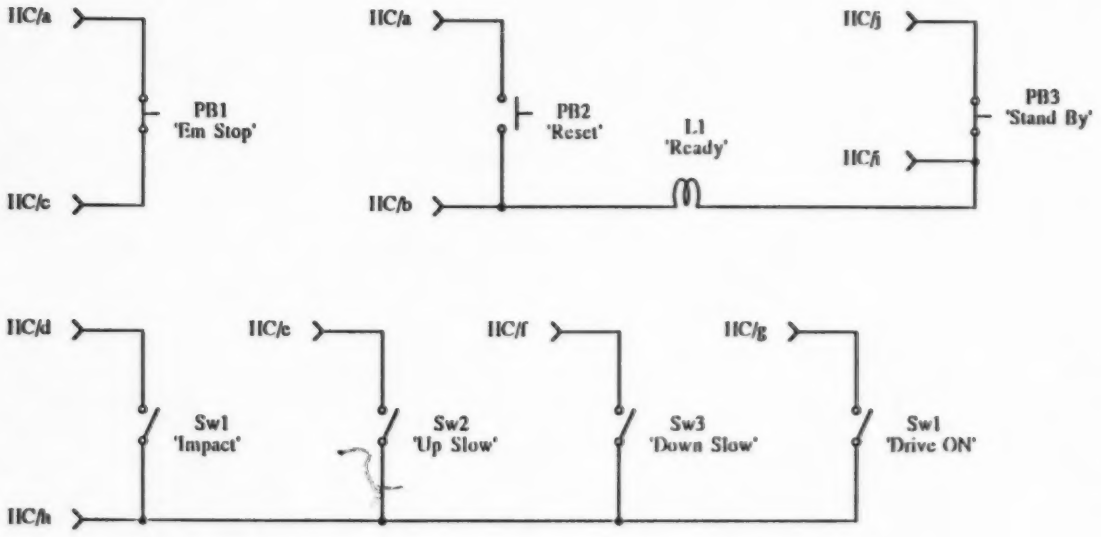


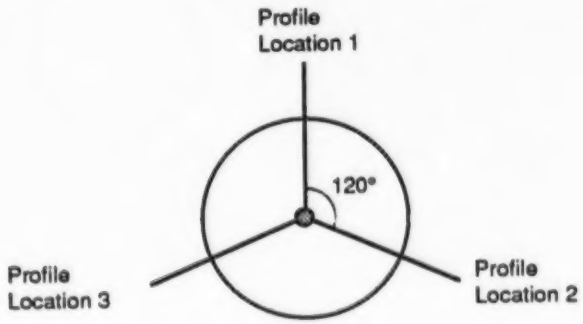
Figure 2.7

Schematic For Handheld Control Box

ARCTEC CANADA LTD.	
IMPACT / ABRASION MACHINE Handheld Control Box	
Date: 8/Feb/1988	Drawn by: D. Frere

Notes: 1. Em. Stop: Shuts down all systems.
2. Reset: Enables operation of solenoid valves & drive motor.
3. Stand By: Disables solenoid valves and drive motor.





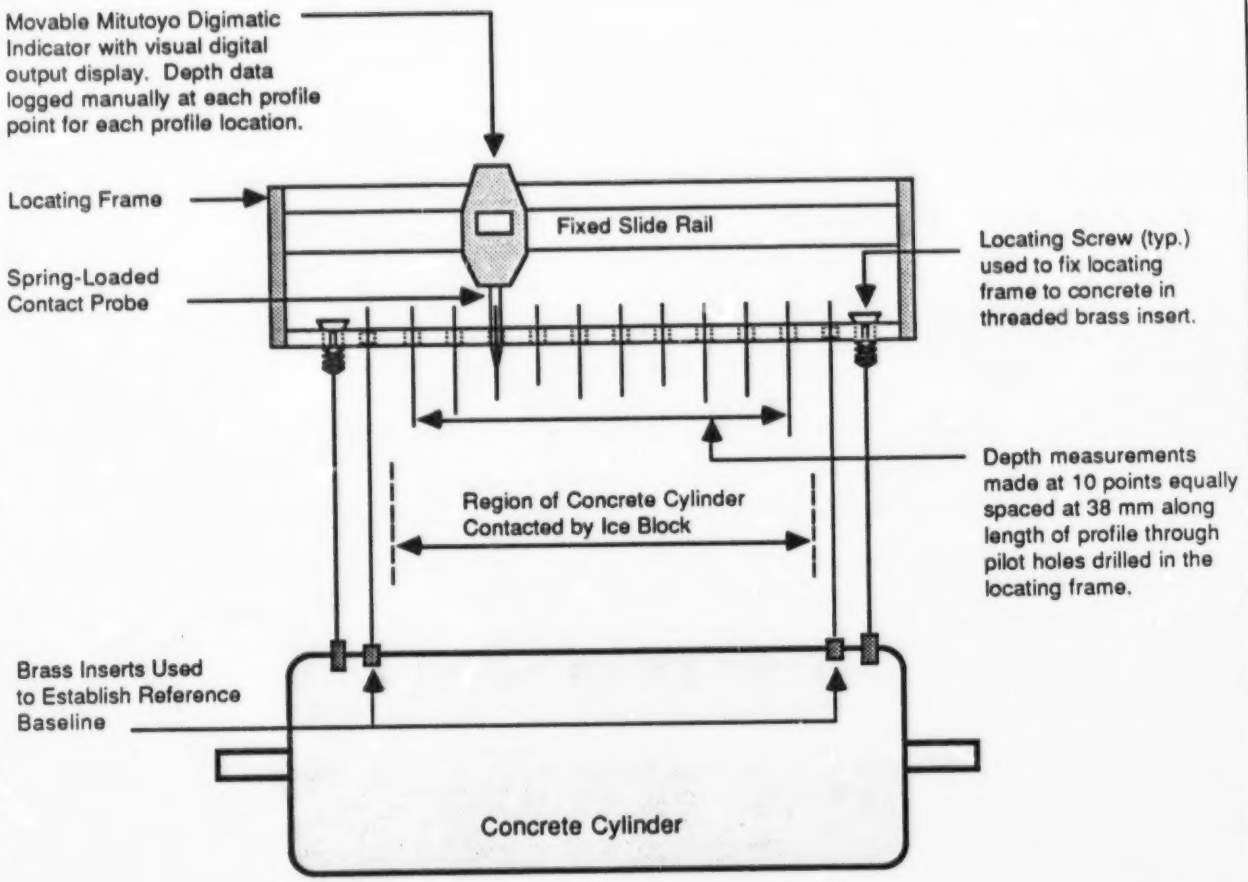

Movable Mitutoyo Digimatic Indicator with visual digital output display. Depth data logged manually at each profile point for each profile location.
Locating Frame
Spring-Loaded Contact Probe
Fixed Slide Rail
Locating Screw (typ.) used to fix locating frame to concrete in threaded brass insert.
Depth measurements made at 10 points equally spaced at 38 mm along length of profile through pilot holes drilled in the locating frame.
Region of Concrete Cylinder Contacted by Ice Block
Brass Inserts Used to Establish Reference Baseline
Concrete Cylinder

Figure 2.8 Schematic of Approach Used to Measure Wear Of the Concrete Cylinders

Concrete Impact/Abraision Tests - Cylinder Wear Raw Data Sheet

Test Number:_____ Test Start Date: _____

Concrete Cylinder Texture:_____ Test Completion Date: _____

Concrete Mixture Series:_____ Cylinder Mixture Date:_____

Profile Data

Date:_____ Time:_____ By:_____

Total No. of Impacts: _____ Total Cumulative Hours of Abrasion: _____ Ice Block Number: _____

Sample Point No.	Dist. from Zero Reference (mm)	Depth (mm) to Concrete Cylinder Profile Location #1			Depth (mm) to Concrete Cylinder Profile Location #2			Depth (mm) to Concrete Cylinder Profile Location #3		
		Profile #1	*Profile #2*	*Profile #3*	*Profile #1*	*Profile #2*	*Profile #3*	*Profile #1*	*Profile #2*	*Profile #3*
0	Zero Ref.									
1	45									
2	83									
3	121									
4	159									
5	197									
6	235									
7	273									
8	311									
9	349									
10	387									

Comments & Sketches:

Photos Taken:_____ Roll No:_____ Photo No's:_____

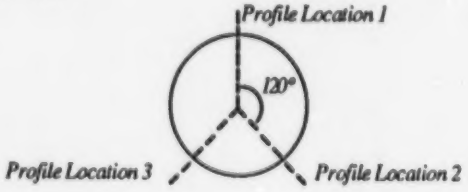


FIGURE 2.10
Sample Spreadsheet Output: Profile Data Referenced to Profile Data Measured at Start of Test

Concrete Impact/Abrasion Tests - Wear Measurements

Test Number: 5
Concrete Sample: 12
Concrete Mixture No.: 4
Concrete Surface: Rough

Test Type: Impact - Abrasion
Cumulative Hours of Abrasion: 129
Cumulative No. of Impacts: 450

	Location 1					Location 2					Location 3				
	Profile Ref. Depth (mm)	Profile Depth (mm)	Profile Depth (mm)	Profile Depth (mm)	Avg. Pt. Wear (mm)	Profile Ref. Depth (mm)	Profile Depth (mm)	Profile Depth (mm)	Profile Depth (mm)	Avg. Pt. Wear (mm)	Profile Ref. Depth (mm)	Profile Depth (mm)	Profile Depth (mm)	Profile Depth (mm)	Avg. Pt. Wear (mm)
Pt.1	4.858	5.045	5.051	5.046	0.189	5.761	5.614	5.610	5.596	-0.154	4.171	4.596	4.609	4.610	0.434
Pt. 2	5.132	5.126	5.122	5.124	-0.008	5.083	5.140	5.137	5.142	0.057	3.354	3.677	3.683	3.697	0.332
Pt. 3	5.095	5.202	5.207	5.226	0.117	4.618	4.737	4.721	4.696	0.100	3.632	3.944	3.957	3.931	0.312
Pt. 4	4.507	4.672	4.666	4.666	0.161	4.998	4.936	4.935	4.931	-0.064	3.480	3.820	3.820	3.840	0.347
Pt. 5	4.975	5.095	5.071	5.095	0.112	4.275	4.401	4.400	4.401	0.126	2.773	3.236	3.233	3.204	0.451
Pt. 6	4.566	4.942	4.950	4.942	0.379	4.408	4.575	4.533	4.532	0.139	3.203	3.660	3.651	3.649	0.450
Pt. 7	3.918	4.600	4.592	4.590	0.676	4.527	4.471	4.420	4.454	-0.079	3.073	3.481	3.464	3.478	0.401
Pt. 8	5.054	5.103	5.137	5.083	0.054	3.845	4.009	3.996	4.006	0.159	2.142	2.610	2.620	2.604	0.469
Pt. 9	3.974	4.516	4.519	4.521	0.545	4.142	4.288	4.273	4.271	0.135	2.954	3.173	3.187	3.183	0.227
Pt. 10	3.985	4.229	4.209	4.200	0.228	4.217	4.270	4.239	4.244	0.034	2.196	2.600	2.613	2.616	0.414
2nd 0	-1.455	-1.201	-1.198	-1.238		-1.181	-1.126	-1.130	-1.239		-1.708	-1.489	-1.505	-1.504	
Profile Area (mm^2)	1697.12	1788.25	1788.11	1787.02		1682.44	1704.66	1698.15	1698.55		1138.56	1278.63	1279.99	1279.01	
Avg. Wear (mm) Over Profile		0.23?	0.232	0.229	0.231		0.057	0.040	0.041	0.046		0.356	0.360	0.357	0.358

FIGURE 2.11

Sample Spreadsheet Output: Profile Data Referenced to Zero-Wear Baseline Established on Cylinder

Concrete Impact/Abrasion Tests - Wear Measurements

Test Number: 5

Concrete Sample: 12

Concrete Mixture No.: 4

Concrete Surface: Smooth

Test Type: Impact - Abrasion

Cumulative Hours of Abrasion: 129

Cumulative No. of Impacts: 450

	Location 1					Location 2					Location 3				
	Profile Ref. Depth (mm)	Corrected Wear (mm)	Corrected Wear (mm)	Corrected Wear (mm)	Avg. Pt. Wear (mm)	Profile Ref. Depth (mm)	Corrected Wear (mm)	Corrected Wear (mm)	Corrected Wear (mm)	Avg. Pt. Wear (mm)	Profile Ref. Depth (mm)	Corrected Wear (mm)	Corrected Wear (mm)	Corrected Wear (mm)	Avg. Pt. Wear (mm)
Pt.1	4.858	0.159	0.165	0.164	0.163	5.761	-0.153	-0.157	-0.159	-0.156	4.171	0.401	0.416	0.417	0.411
Pt. 2	5.132	-0.057	-0.061	-0.051	-0.057	5.083	0.046	0.044	0.071	0.053	3.354	0.279	0.288	0.302	0.290
Pt. 3	5.095	0.031	0.035	0.066	0.044	4.618	0.103	0.088	0.095	0.095	3.632	0.246	0.264	0.238	0.249
Pt. 4	4.507	0.066	0.059	0.074	0.066	4.998	-0.083	-0.083	-0.044	-0.070	3.480	0.255	0.261	0.280	0.265
Pt. 5	4.975	-0.002	-0.027	0.016	-0.004	4.275	0.100	0.101	0.154	0.118	2.773	0.358	0.363	0.333	0.351
Pt. 6	4.566	0.229	0.235	0.250	0.238	4.408	0.135	0.095	0.158	0.129	3.203	0.330	0.330	0.328	0.329
Pt. 7	3.910	0.512	0.502	0.527	0.513	4.527	-0.093	-0.141	-0.034	-0.089	3.073	0.261	0.255	0.268	0.262
Pt. 8	5.054	-0.144	-0.112	-0.136	-0.131	3.845	0.122	0.112	0.205	0.147	2.142	0.302	0.324	0.307	0.311
Pt. 9	3.974	0.324	0.324	0.360	0.336	4.142	0.099	0.087	0.179	0.122	2.954	0.031	0.058	0.054	0.048
Pt. 10	3.985	0.003	-0.020	0.009	-0.003	4.217	0.001	-0.026	0.082	0.019	2.196	0.196	0.224	0.226	0.215
2nd 0	-1.455					-1.181					-1.708				
Profile Area (mm^2)	41.605	40.883	47.593			11.494	5.760	27.415			97.372	101.845	100.672		
Avg. Wear (mm) Over Profile	0.106	0.104	0.121	0.110		0.029	0.015	0.070	0.038		0.248	0.259	0.256	0.254	

3. REFERENCES

Arctec Canada Limited, 1987, "Determination of the Resistance of Concrete to Abrasion and Impact by Ice Under Offshore and Arctic Conditions", contractor report 1585-2, submitted by Arctec Canada Limited to CANMET, Energy, Mines and Resources, Canada.

Nawwar, A., Roots, T., and Berry, E., 1988, "Development of Methods for Testing the Resistance of Concrete to Ice Abrasion and Impact: Phase I Report", contractor report 1585-1 submitted by Arctec Canada Limited to CANMET, Energy, Mines and Resources, Canada.

Roots, T., Nawwar, A., and Malhotra, V.M., 1986, "Development of a Test Method to Determine the Resistance of Concrete to Ice Abrasion and/or Impact", proc. CSCE/CANMET International Workshop on Concrete for Offshore Structures, St. John's, Newfoundland.

APPENDIX A

SPECIFICATIONS

MANUAL NO. 3009

Operation Manual/取扱説明書

543 Series
Digimatic Indicator
デジマチックインジケータ

MITUTOYO

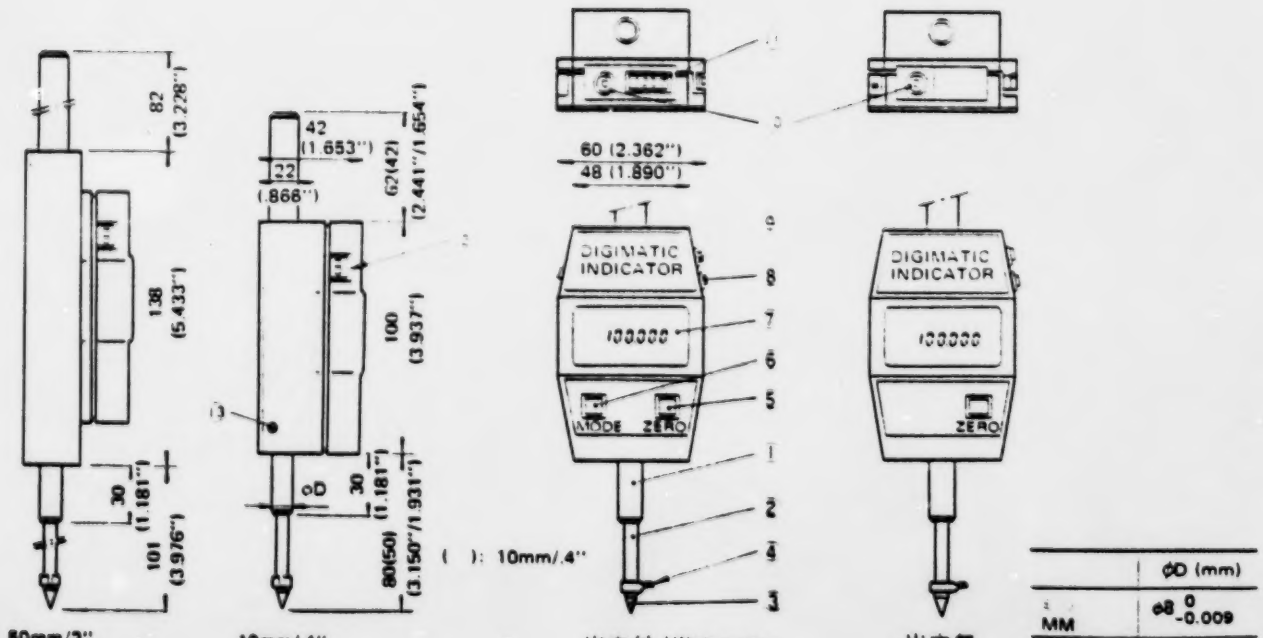


Fig. 1

	ϕD (mm)
MM	$\phi 8^{\ 0}_{-0.009}$
MM/INCH	$\phi 9.52^{\ 0}_{-0.03}$

8. 仕　様

8. SPECIFICATIONS

最小表示量 Resolution	測定範囲 Range	出　力 / Data Output				精　度 Measuring accuracy	ステム径 Stem dia.	表　示 Display
		有 / With		無 / Without				
0.001mm	10mm	543-411	543-411-1	543-211	543-211-1	2μm	φ8 $^{0}_{-0.009}$mm	蛍光表示管（緑）6桁、（－）符号
	30mm	543-413	543-413-1	543-213	543-213-1	3μm		
	50mm	543-415	543-415-1	543-215	543-215-1	5μm		
0.01mm	10mm	543-431	543-431-1	543-231	543-231-1	5μm		
	30mm	543-433	543-433-1	543-233	543-233-1	8μm		
	50mm	543-435	543-435-1	543-235	543-235-1	10μm		
.0001" (0.001mm)	.4"(10mm)	543-421	543-421-1	543-221	543-221-1	.0001" (2.5μm)	φ3/8"	Fluorescent tube (green) 6-digit, (-) sign
	1.2"(30mm)	543-423	543-423-1	543-223	543-223-1	.00015"(4μm)		
	2" (50mm)	543-425	543-425-1	543-225	543-225-1	.00025"(6μm)		
.001" (0.01mm)	.4"(10mm)	543-441	543-441-1	543-241	543-241-1	.0002" (5μm)		
	1.2"(30mm)	543-443	543-443-1	543-243	543-243-1	.00035"(9μm)		
	2" (50mm)	543-445	543-445-1	543-245	543-245-1	.0004" (10μm)		

AC-アダプタ / AC-adapter	付 / with	無 / without	付 / with	無 / without
機能 / Function	• ゼロセット • ディレクション • 最大値・最小値のホールド	• Zero set • Direction • MAX. MIN. HOLD	• ゼロセット • ディレクション	• Zero set • Direction

● 標準付属品
No.540774 レリース（10、30mmのみ）
No.137693 リフティングレバー（30、50mmのみ）

● Standard accessories
No. 540774 Release, except for 50mm(2")
No. 137693 Lifting lever, except for 10mm(.4")

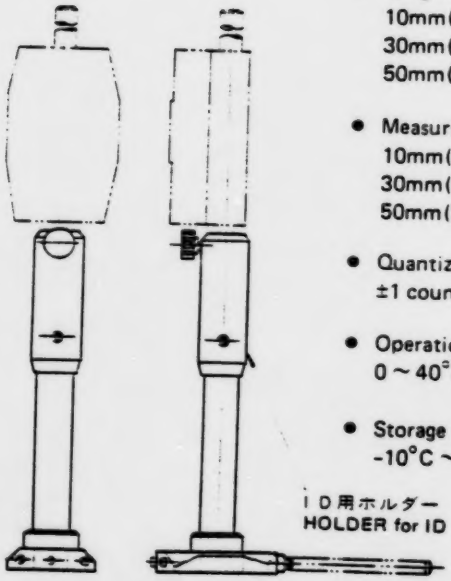
● 質　量
10mm……290g
30mm……300g
50mm……400gr

● 測定力
10mm……1.47N以内
30mm……1.76N以内
50mm……2.94N以内

● 量子化誤差
±1カウント以内

● 使用温度
0 ～40℃

● 保存温度
－10℃ ～60℃



ID用ホルダー
HOLDER for ID

● Weight
10mm(.4") . . . 290g
30mm(1.2"). . . 300g
50mm(2.0"). . . 400gr

● Measuring force
10mm(.4") . . . 1.47N or less
30mm(1.2"). . . 1.76N or less
50mm(2.0"). . . 2.94N or less

● Quantizing error
±1 count or less

● Operation temperature
0 ～ 40°C

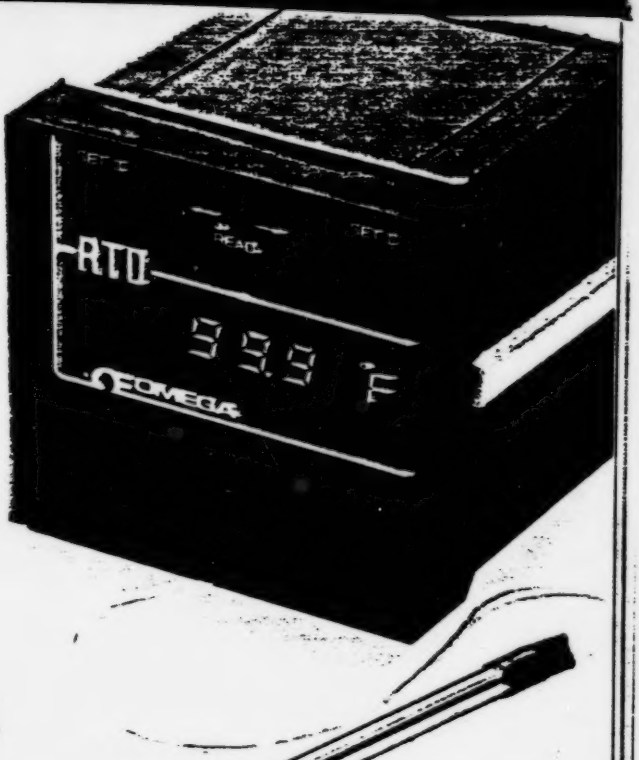
● Storage temperature
-10°C ～ 60°C

● 特別付属品
No.902384　シリンダゲージ用ホルダ（545シリーズにID 10mmをセットするのに用います）

● Optional accessory (Holder to instll 10mm/.4" ID)
No. 902384 (mm) Holder for bore gage (545 series)
No. 902372 (inch) Holder for bore gage (545 series)

RTD Digital Controllers

- High accuracy: to 0.1% of span
- Single and dual set points
- 1.0° and 0.1° models
- Adjustable proportion band
- Bright LED Display



2 YEAR
WARRANTY

Probe not included.
See Section E.

General:

The OMEGA 4200 series is an ideal controller for RTD applications. This quality built linearized instrument is available in both 1.0° and 0.1° resolution models. Higher accuracies, accuracies 5 to 10 times greater than the typical 1% meter indicating controller, are achieved through a unique linearizing technique.

Bright, easy to read, LED digits present an unambiguous temperature indication. Accuracy is enhanced through 3 wire lead compensation — a feature allowing the sensor to be up to 1000 ft. from the controller. The standard unit includes adjustable proportional band, manual reset, plus a metal 1/4 DIN case with full plug-in construction allowing front removal of the control unit without disturbing the case and its rear wiring. The series 4200 controllers are available in single and dual setpoint models with relay output as a standard. Triac or 4-20 mA Optional outputs are offered on the first set point at no additional cost. Truly a superior controller at remarkably low price.

Model 4201 Single Set-Point Proportional Controller — $305

This versatile digital controller can be operated as a proportional controller with the adjustable band width up to 3[illegible] of full span. The set-point temperature is always available. Simply push the spring loaded set-point switch to the right and the set-point is digitally displayed. To change the set point, with the switch deflected to the right adjust the knob to the right of the switch until you get the desired reading. The standard Model 4201 has an internal SPDT relay (7 amp resistive at 120 VAC). This model is also available with optional Triac or 4-20 mA output in place of the relay. These options are covered in the Option and Specification sections.

Model 4202 Dual Set-Point Controller — $340

The first set-point of the Model 4202 incorporates the same features as the Model 4201 and also can be furnished with the optional Triac or 4-20 mA output.

The second set-point may be set at any value within the full span of the controller. It energizes a SPDT internal relay (3 amp resistive 120 VAC) which can be used as either an on-off control, a high limit alarm, or a low limit alarm. For an alarm with latching features an external latching relay and push button to reset are suggested.

The second set-point is set and displayed using the same procedure as for the Model 4201 except the switch is deflected to the left and the left adjustment knob is used.

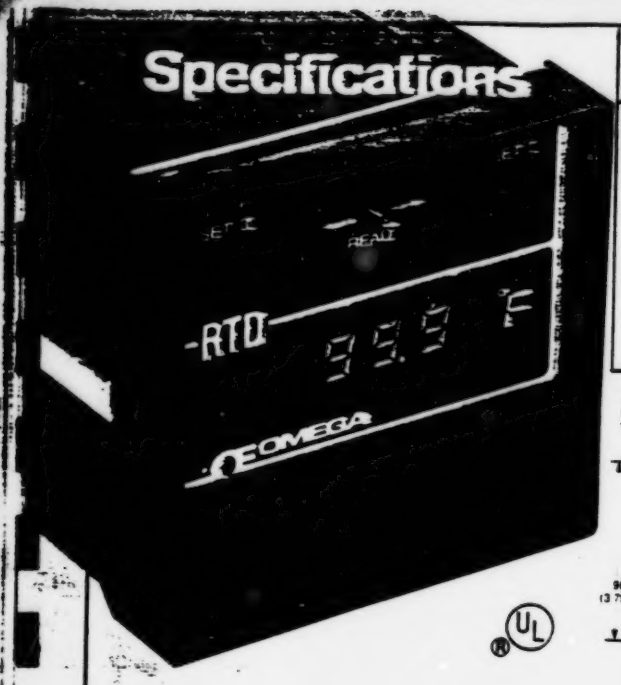
Option "T" Triac Output No Additional Charge.

Option "T" replaces the relay output on the first set point with a solid state plug-in Triac which yields time proportional, or on-off switching. The Triac is rated at 2 amps continuous and 10 amps in rush for both 120/240 VAC service. For higher amperage loads the Triac may be used to drive higher rating solid state relays or mechanical contactors. Specify "Option T" after the model number when ordering.

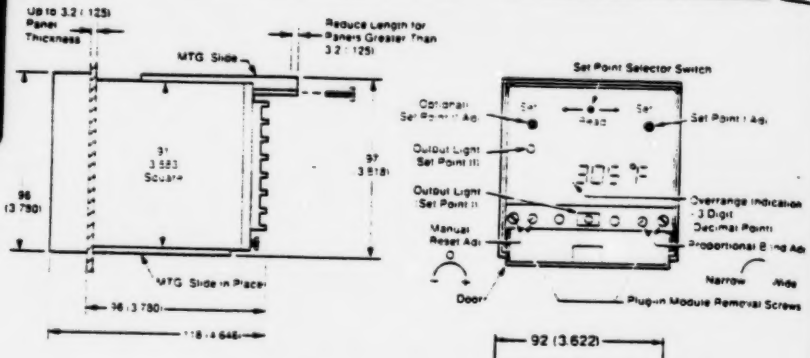
Option "F" (4-20 mA Output) No Additional Charge

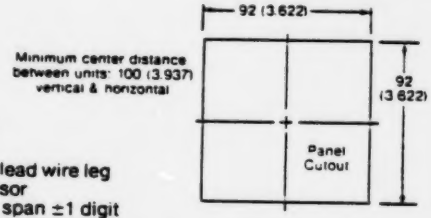
This option is applicable to the first set point only and is used to drive proportioning devices such as SCR power controller, motor positioners or electropneumatic actuators. The 4-20 mA dc output signal can be connected to a maximum of 1000 ohm resistance load. This signal is 20 mA at the low temperature end of the proportional band and is decreased linearly thru the band to 4 mA at the high temperature end. If the driven device is not isolated (ungrounded) an ungrounded sensor must be used with the Series 4200 which is designed for only one ground in the system. When ordering call out "Option F" after the model number.

Specifications



Sensor Type	Range	Resolution	Accuracy ±1 digit	Number of Set Points	Model	Price
100 ohm Platinum RTD α = .00385 ohm/ohms/°C	0 to 999°F 0 to 600°C	1°F 1°C	±0.1% of Span	Single	4201 PF1 4201 PC1	$305 $305
	0 to 999°F 0 to 600°C	1°F 1°C		Dual	4202 PF1 4202 PC1	$340 $340
	−199.9 to +199.9°F −199.9 to +199.9°C	0.1°F 0.1°C	±0.2% of Span	Single	4201 PF2 4201 PC2	$305 $305
	−199.9 to +199.9°F −199.9 to +199.9°C	0.1°F 0.1°C		Dual	4202 PF2 4202 PC2	$340 $340





Minimum center distance between units: 100 (3.937) vertical & horizontal

RTD Input

Type	100 ohm platinum alpha = 0.00385 (DIN curve)
Configuration	3 wire
External Lead Wire Resistance Effect	0.1% span up to 10 ohms per lead wire leg
Sensor Break Protection	Built-in, upscale on open sensor
Calibration Accuracy	1.0° resolution model, ±0.1% span ±1 digit 0.1° resolution model, ±0.2% span ±1 digit
Stability	0.1% for 30 −130°F, 0.1% +10%−15% line voltage
Common mode rejection	Max error ±1°C with 240V, 60Hz applied as common mode signal between sensor input and chassis ground.
Series mode rejection	Max error ±1°C with series mode signal of 100 MV PK-to-PK at 60 Hz

Control Output

1st. Set-Point (Adjustable time proportional)	
Relay (Standard Model)	SPDT relay 7 amps resistive at 120 VAC, 5 amps resistive at 240 VAC
Option "T" (Triac)	Solid state plug-in triac rated 2 amp holding and 10 amps in-rush
Option "F" (Current Proportional)	4-20 ma (DC) into 1000 ohm max
2nd. set point	
Relay (on-off only)	SPDT, rated 3 amps at 120 VAC

Adjustments

Proportional Band (gain)	0-3% of span
Manual Reset (off-set)	Adjustable
Cycle time	Automatically adjusts with band adjustment to give least wear with minimum ripple (10 sec. minimum total time).

Display and Indications

Temperature	Filtered LED, 3 or 3½ digits, 2 reading per second update. Readability is 1.0° or 0.1° (°F or °C) depending on model
Set-Point	By spring loaded switch, 1st or 2nd set-point is displayed in place of temperature. Set-Point adjusted by 25 turn pot. 1.0° or 0.1° Setability.
Outputs	LED indication for both 1st and 2nd set-points. LED are "on" when output drive signal present. "On-off" indication on relay and triac model. Proportional intensity for option "F".
Temperature overrange	Red LED indication.

Setpoint

Resolution	1.0° or 0.1° (°F or °C) depending on model
Repeatability	±0.1% to ±0.2% of span
Adjustment	By 25 turn pot. See "Set Point" under "Display and Indication" section.
Power	120/240 VAC (+10%, −15%), 50/60 Hz. Power consumption less than 5 watts.

Environmental & Physical

Operating temperature	30-130°F
Weight	2 lb.
¼ DIN Case	Metal, full plug in, with screw terminal on rear. Adjustable brackets for panel mounting. Panel cut out is 3.622" vertical and horizontal dimensions.

Specifications and configurations are subject to change as advances in technology allow.